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REMOTE TELE-ASSISTANCE SYSTEMS FOR MAINTENANCE OPERATORS IN MINES

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ABSTRACT: Complex technologies such as fully automated and semi-automated equipment and teleoperated machines are being introduced to improve productivity in mines. Consequently, the maintenance and operation of these complex machines is becoming an issue. There is a growing interest in industry in the use and development of technologies to support the collaboration between a local worker and a remote helper to deliver expertise to guide the local worker in undertaking maintenance and other activities. The productivity of the future mine relies on the effective delivery, of remote guidance. ReMoTe (Remote Mobile Tele-assistance), a mobile augmented reality system for remote guiding, has been developed at CSIRO as part of the work in the Transforming the Future Mine Theme.

INTRODUCTION

In the industrial and mineral extraction fields, complex technologies such as fully automated and semi-automated equipment or teleoperated machines are being introduced to improve productivity. Consequently, the maintenance and operation of these complex machines is becoming an issue. Operators/technicians rely on assistance from expert in order to keep their machines functioning. Personnel with such expertise, however, are not always physically located in close proximity to the equipment/machine. They are often in a major metropolitan city while the technicians maintaining equipments are in rural areas, where industrial plants or mine sites may be located. There is a growing interest in industry in the use and development of technologies to support the collaboration between a local worker and a remote helper. For example, in telemedicine, a specialist doctor may guide remotely a non-specialist doctor or a nurse (Palmer, *et al.*, 2007); in remote maintenance, an expert may be guiding remotely a technician through the task of repairing a piece of equipment (Kraut, *et al.*, 2003). Communication means that have been used for this purpose include telephone, email and basic video conferencing. It is generally accepted that augmented reality technology is very useful in maintenance and repair applications (Lapkin, *et al*., 2009).

ReMoTe is a remote guiding system developed for the mining industry. ReMote was designed to support the mobility aspect of maintenance workers. In ReMoTe, the expert, when guiding remotely a worker, uses his/her hands not only to point to remote location - “grab this” - but also to demonstrate how to perform a specific manual procedure. The potential of applying a non-mediated hand gesture communication, a proven effective technique of communication, in the field of wearable augmented reality is explored. A review of the literature on augmented reality (AR) remote guidance systems used in industry is followed by some initial results of ReMoTe testing and a short description of future work.

AUGMENTED REALITY REMOTE GUIDING SYSTEMS FOR MAINTENANCE

Automated AR based remote guiding systems

Augmented reality (AR) systems have been developed since 1990 to assist maintenance workers in various industries in conducting their tasks. In order to minimize the risk of errors, relevant information was projected onto the machine in real time (using AR) to assist operators in repairing the machine. One key benefit of the use of AR is that the attention of the operator is on the maintenance task not on the system delivering the help. Many studies were conducted in the early 2000 to evaluate the benefits of AR in the area of maintenance. Identifying the exact location of the required intervention helps reduce the transition between tasks (Henderson and Feiner, 2009), AR based guiding is better than paper based instruction for guiding an assembly task (Wiedenmaier *et al.*, 2003), leading to a reduction in the number of errors. When comparing paper based instruction and AR based guiding, the AR based guiding system allow users to stay on task; there is no need to switch attention to a piece of paper to look for specific information and hence a reduced cognitive load (Henderson and Feiner, 2009).

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One of the early AR guiding System being developed for the maintenance of laser printing machines is the KARMA system (Feiner Macintyre and Seligmann, 1993). The system used an optical see through display. Boeing in 1992 developed its own AR guiding system to help their technicians in the electric cabling of Boeing planes (Caudell and Mizell, 1992). This system was based on real time annotation of videos based on operator tasks. The ARTESA project (ARVIKA, 1999) at Siemens started in 1999 and aimed at further exploring the use of AR in industrial applications. As in the Boeing project, ARTESA relied on instrumentation of the workspace of the operator in order to localize him/her. Augmented information in the form of text (Figure 1) and 3D images based on the specific context of the operator's task were generated (Weidenhausen *et al*., 2003).

Figure 1 - Augmentation in the form of text in ARTESA (ARVIKA, 1999)

Subsequent efforts at Siemens (2004 to 2006) have been focusing on developing marker-less tracking as well as looking at ergonomic considerations. BMW has also explored the use of AR for guiding its maintenance workers (Platonov, *et al.*, 2006) using a see through system (Figure 2). The system uses a database of images of a system to detect specific features, which are then registered onto a CAD model. The guiding system detects features from the video of maintenance worker and compares them with the preregistered features in order to determine the orientation of the worker.

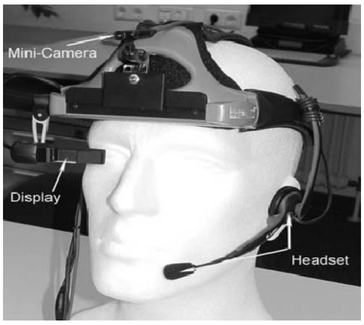

Figure 2 - BMW AR system (after Platonov *et al.*, 2006)

In project ARMAR (Augmented Reality for Maintenance and Repair), Henderson and Feiner (2003, 2010) have been interested in exploring the extent to which AR can increase the productivity, the precision and safety of maintenance personnel. The AR system uses a binocular video see through system (see Figure 3).

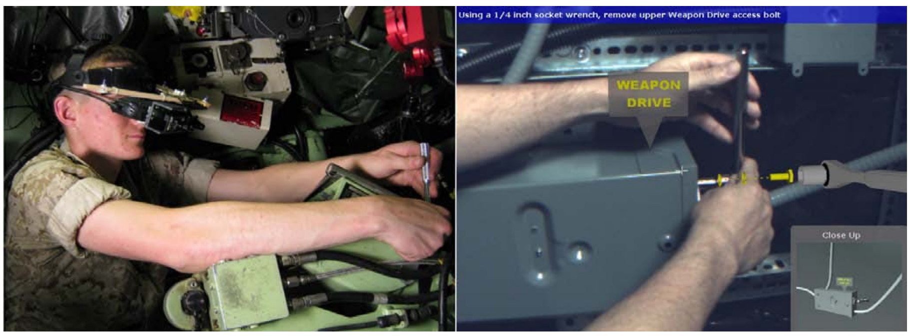

Figure 3 - ARMAR system (after Henderson and Feiner, 2010)

The last two systems are the more developed AR systems to date for guiding a maintenance worker in performing a standard procedure. These systems cannot guide the worker in situations where there is no predefined way of solving the problem. In such a situation, there is a need to involve a remote expert.

Tele-supervised AR remote guiding systems

Kuzuoka *et al.* (2004) developed a system for supporting remote collaboration using mobile robots as communication media. The instructor controls the robot remotely and the operator receives instructions via the robot. In this system, the robot is mounted by a three-camera unit for the environment of the operator. It also has a laser pointer for hitting the intended position and a pointing stick for indicating the direction of the laser pointer. The movement of the robot is controlled by the instructor using a joystick.

Sakata and Kurata (Sakata, *et al.*, 2003; Kurata, *et al.*, 2004) developed the Wearable Active Camera/Laser (WACL) system that involves the worker wearing a steerable camera/laser head. WACL allows the remote instructor not only to independently look into the worker's task space, but also to point to real objects in the task space with the laser spot. As shown in Figure 4 the laser pointer is attached to the active camera-head and it can point a laser spot. Therefore, the instructor can observe the environment around the worker, independently of the worker's motion, and can clearly and naturally instruct the worker in tasks.

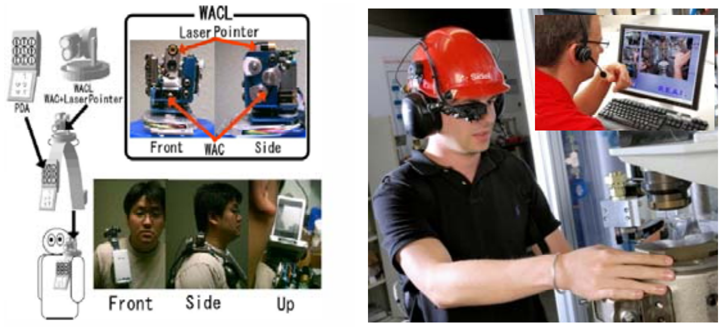

Figure 4 - The WACL (left, after Kurata, *et al.*, 2004) and the REAL system (right, after REAL)

Previous work in the area of remote guiding of mobile workers has mostly focused on supporting pointing to remote objects and/or remote area using a projection based approach, such as the laser pointing system in WACL (Sakata, *et al.*, 2003; Kurata, *et al.*, 2004) or using a see through based approach, such as in REAL; (see Figure 4). While pointing (with a laser or a mouse) is an important aspect of guiding, research has indicated that projecting the hands of the helper supports a much richer set of non-verbal communication and, hence, is more effective for remote guiding (Li, *et al.*, 2007; Kirk, *et al.*, 2006; Fussell, *et al.*, 2004).

The next section presents ReMoTe a remote guiding system developed for the mining industry. In Remote, the expert, when guiding remotely a worker, uses his/her hands not only to point to remote location - "grab this" - but also to demonstrate how to perform a specific procedure "you grab this way and push it this far from the wall".

THE REMOTE SYSTEM

The ReMoTe, system has been developed to address the above needs. In particular, ReMoTe captures the hand gestures of the helper and projects them onto a near-eye display worn by the worker. It is composed of 1) a helper user interface used to guide the worker remotely using a touch screen device and an audio link, and 2) a mobile worker system composed of a wearable computer, a camera mounted on a helmet and a near eye display (Figure 5).

Helper interface

A participatory approach for the design of the helper interface was adopted. The aim was to design a system that would fulfil the users' needs and be as intuitive to use as possible. The initial step consisted of observing maintenance workers and developing a set of requirements for the helper-user interface (UI) based on our understanding of their needs including:

- The need for supporting complex hand movements such as: "take this and put it here", "grab this object with this hand", and "do this specific rocking movement with a spanner in the other hand".
- Mobility of the worker during the task, as they move from being in front of the machine to a tool area where they access tools, to the back of the machine to check components, such as valves.
- The need to point/gesture in an area outside the field of view of the worker, hence the need to provide the helper with a panoramic view of the remote workspace.

Figure 5 - Worker interface

Subsequently, a first sketch of the interface was produced consisting of a panoramic view of the workspace and a video of the worker's view. The video provides a shared visual space between the helper and the worker that is used by the helper for pointing and gesturing with their hands (using unmediated gesture). This shared visual space augmented by the helper's gestures is displayed in real time on the near eye display of the worker (image + gestures). The helper UI consists of:

- A shared visual space which displays, by default, the video stream captured by the remote worker's camera. This space occupies the central area of the touch table.
- A panoramic view of the worker's workspace, which the helper can use for maintaining an overall awareness of the workspace. This view can also be used by the helper for bringing the worker to an area that is outside their current field of view. The panoramic view occupied the lower end of the touch table.
- Four storage areas, two on each side of the shared visual space, to allow the helper to save a copy of the shared visual space. For instance, a particular instruction/gesture on a particular object may be reused in the collaborative task at a later stage of the collaboration.

Remote technical specifications

The platform draws on previous experience in the making of the REAL system, a commercial, wearable, low-power augmented reality system employing an optical see trough visor (LiteEye 750) for remote maintenance in industrial scenarios. In particular, ReMoTe makes use of the XVR platform, a flexible, general-purpose framework for VR and AR development. The architecture of the system is organized around two main computing components: the worker wearable device and the helper station, as seen in Figure 6.

Wearable computers usually have lower computing capability compared to desktop computers. To take into account the usual shortcomings of these platforms, software has been developed using an Intel Atom N450 as a target CPU (running Microsoft Windows XP). It presents reasonable heat dissipation requirement and peak power consumptions below 12 watts, easily allowing for battery operation. A Vuzix Wrap 920 HMD mounted on a safety helmet was used as the main display of the system. The arrangement of the display is such that the upper part of the workers field of view is occupied by the HMD screen. As a result, the content of the screen can be seen by the worker just looking up, while the lower part remains non-occluded. With such an arrangement, what is displayed on the HMD gets used as a reference, but then the worker performs all his/her actions by directly looking at the objects in front of him/her. CMOS USB camera (Microsoft Lifecam HD) is mounted on top of the worker's helmet (as seen in Figure 6). This allows the helper to see what the worker is doing in his/her workspace. A headset is used for the worker-helper audio communication.

Figure 6 - The helper control console (left) and the worker wearable unit (right)

The main function of the wearable computer is to capture the live audio and video streams, compress them in order to allow network streaming at a reasonable low bit rate, and finally deal with typical network related issues like packet loss and jitter compensation. To minimize latency a low level communication protocol based on UDP packets is used, data redundancy and forward error correction, gives the ability to simulate arbitrary values of compression/decompression/network latency, with a minimum measured value around 100 ms. Google's VP8 video compressor is used for video encoding/decoding, and the Open Source SPEEX library is used for audio, with a sampling rate of 8 kHz. It should be noted that at the same time the wearable computer also acts as a video/audio decoder, as it receives live streams from the helper station and renders them to the local worker.

The main component of the helper station is a large (44 inches) touch-enabled display. The display is driven by NVidia GeForce graphic card mounted on a Dual Core 2.0 GHz Intel workstation (Windows XP). The full surface of the screen is used as a touch-enabled interface, as depicted in Figure 7.

Figure 7 - Layout of the helper screen

Occupying the central portion of the screen is an area that shows the video stream captured by the remote worker camera: it is on this area that the helper is using his/her hands to guide the worker. On the side of the live stream, there are four slots, initially empty, where at any moment it is possible to copy the current image of the stream. This can be useful to store images of particular importance for the collaborative task, or snapshots of locations/objects that are recurrent in the workspace. Another high-resolution webcam (Microsoft Lifecam HD) is mounted on a fixed support attached to the frame of the screen, and positioned to capture the area on the screen where the video stream is displayed in Figure 9: the camera capture what is shown on the touch screen (see arrow 1) and the hand performed by the helper over that area (see arrow 2).The resulting composition (original image plus the hand gesture on top) is once again compressed and streamed to the remote worker, to be displayed on the HMD (see arrow 3). The overall flow of information is represented in the diagram of Figure 8.

Remote design and initial testing

Four design iterations of our UI were performed, testing and validating each design with a set of representative end users on the following three maintenance/repair tasks (Figure 9):

- Repairing a photocopy machine;

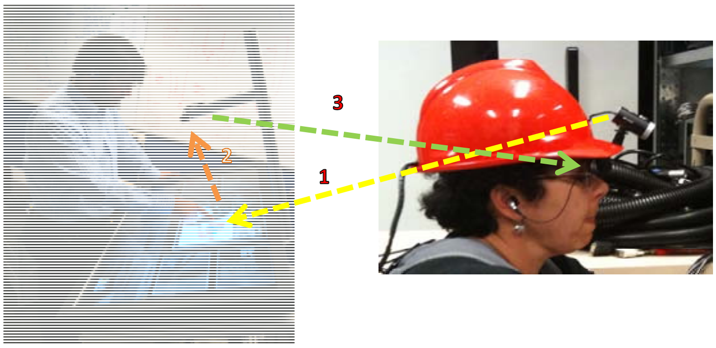

Figure 8 - Data capture and display

Figure 9 - Maintenance and assembly task

- Removing a card from a computer mother board and
- Assembling a Lego toy.

Over 12 people have used and trialled the system, providing valuable feedback on how to improve the helper UI and more specifically the interactive aspect of the UI: the selection of a view, the changing of the view in the shared visual space and the storage of a view. The aim was to perform these operations in a consistent and intuitive manner, for ease of use. The overall response from the representative end users pool is that the system is quite intuitive and easy to use. No discomfort has been reported to date with the near eye display of the worker system.

FUTURE WORK

The next step in the development of the augmented reality system is to investigate the expansion of the current system to a mobile helper station. In the remote guiding system currently developed the gesture guidance is supported by a large touch table. A fully mobile remote guiding system using similar technologies for the two parts of the system, the expert station and the operator station, will be easily deployable and adaptable in the mining industry.

Currently a rugged version of the system is being engineered for initial field deployment and field studies. Industry deployment and the study of the system in use in its real context is crucial in understanding the human factors and issues prior to prototype development and commercialisation of the system.

The deployment of a rugged ReMoTe system to a mine site would allow investigation of the following questions:

- What is required for mining operators to use the system effectively?
- What measurable benefits can be achieved from the system use in a mine, such as, productivity and safety?
- What ROI on maintenance cost could be obtained by means of a large deployment of several similar units?

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